Chapter 1

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Introduction

This report is a summary of our design work on fish and other aquatic passage on forest and county roads in Southwestern Oregon. In the past 10 years numerous structures were replaced or modified to improve passage. Several designs have worked well. This report discusses many of those projects, provides a brief description of the design methodology, and offers a process for evaluation of alternatives at stream road crossings. A bibliography and glossary are included as an appendix.

This report is a working paper which will be improved and added to over the next several years. Other references are available and I have made references to many of them in this manual. The importance of the work being done by the State of Washington cannot be understated and provided an excellent reference to any fish passage library. Much of their work is currently available on the Web.

http://www.wa.gov/wdfw/hab/engineer/habeng.htm

References and Prototype

When we began work on fish passage structures, we tried to find good examples that worked with technical references that supported their design. Many of those references are included in the bibliography. The solutions proposed in this report for passage of fish and wildlife are not "new" but often another look at older ideas.

This manual was developed to provide guidance for designing road stream crossings. Alternatives at a crossing site can include culverts, fords, bridges, or perhaps a decision to remove the crossing all together. There is no best alternative for all sites. A hierarchy of options is presented in this report with evaluation criteria to assist managers and designers.

DESIGNING CULVERTS FOR FISH PASSAGE

Our original design goal was to design culverts that provided passage of adult and large juvenile fish passage through culverts. We estimated the ability of salmon or trout to swim through a culvert or jump into a culvert from a pool below. That design methodology is now referred to as the "Hydraulic Design method." Culverts are sized or checked for their ability to pass an adult salmonid at high flows and a six-inch trout at low flow. This procedure worked best on sites that were very low gradient or back-watered. Pipes still had long periods during the summer when flow was too shallow for passage.

While working on several projects with Professor John Orsborne, we learned about placing weirs and baffles in culverts to create a series of cascading pools. We contacted several manufacturers and developed a sloping weir as a self cleaning fish way. The fishway is built into the culvert at the factory. Improvements to our original design have included removing the weir jumps, optimization of the design at the inlet and outlets, sizing the pipes to remove inlet constrictions and, modifications that have provided passage now for the smaller juvenile fish. This design has been very successful. Passage of juveniles through culverts can be achieved to at least 13% gradients. I refer to this design methodology as the “Fishway Design method.” See Chapter Five for details.

The next significant change in our design methodology occurred as we attempted further improve our crossings for passage of all stream organisms. We had observed that several of our fishway structures had filled in with gravels. Several of our biologists noted that with a gravel substrate provided a better opportunity for the passage of other stream organisms in addition to fish. They argued that if we could design a culvert to retain a natural substrate all sizes and species of fish would be able to move through the structure. This was the same principle we had been following for open bottom structures. The design objective is to simulate a natural channel in the culvert. This type of design is called “stream simulation.”

Goals for selection of Road Stream Structures:

Historically structures were selected for their ability to transport water and debris under a road at the least cost to the owners. Designs were optimized to achieve those goals. Water Quality goals were later added to reduce sedimentation. Other considerations were often given a low priority. Additional goals or emphases are proposed for new structures. I have listed many of them below. These goals at times seem to be at odds with each other.

I. Structures should allow for unobstructed movement of fish at the time the fish are moving.

II. Structures should be consistent with the road system, and it's maintenance expectation:
   1. High use: Public Access Roads
      a. Designed to AASHTO standards
      b. Maintenance of Structures is expected
      c. A temporary closure is a major impact
      d. B.L.M. and USFS call these Level 4 and 5 roads
   2. Medium Use: Public Excess roads:
      a. Public Use may be restricted seasonally.
      b. Designed to Agency Standards. A county must still design to AASHTO standards for public funding.
      c. Maintenance of Structures may be delayed after a major event.
      d. A temporary closure can be made but will require public involvement and potentially a detour road.
      e. BLM and USFS call these Level 3.
   3. Low Use: Administrative Access Roads:
      a. Designed to agency standards as a commercial access road.
      b. Public often has access to roads for recreation use but that access can be administratively closed.
      c. Maintenance of structures may be delayed indefinitely.
      d. BLM and USFS call these Level 2 roads.

III. Structures should adhere to State and Federal Fish and Wildlife guidelines pertinent to the endangered species act.
   1. Continuity of the ecosystem
   2. Crossing barriers to selected species
   3. Human disturbances to the habitat.

IV. Structures should have adequate diversion potential or "storm proofing."

V. Structures should, as a minimum, be adequate for a design storm event of 100 years. (Q 100).

VI. Structures should be cost effective.

VII. The construction of Structures should comply with all state and federal law.
   A. OSHA - Workers safety
   B. In stream guidelines for protection of fish and wildlife
   C. Water quality guidelines for sedimentation and turbidity.

VIII. Structures should provide mitigation for future design flows as land uses change.

Fish Movement in streams

As noted above, in-stream structures should allow for movement of fish “when fish are moving.” In order to complete a design or a design review, we make a prediction of the flows in the stream for high fish passage flows and low fish passage flows. This is not an exact science. Data is often limited on the flow variations in a stream and the ranges of times that fish is moving in those reaches. Fish move within streams for some of the following reasons.

IX. Reproduction: Salmon migrating upstream for spawning
X. Habitat: Juvenile and Adult fish move within the system for food protection
XI. Refuge: Fish movement for environmental factors such as elevated stream temperatures, flow conditions and predation.
XII. Life cycle: Moving upstream for a rearing lake or downstream for a freshwater habitat.
XIII. Over-wintering habitat: Coho often will move into tributaries and side channels.
XIV. Genetic programing: Fish move up or down streams looking for habitat that may no longer exist but historically was available.

When do fish move in the streams? The chart below was used to display fish movement in a typical drainage in Coos Bay Oregon.

TYPICAL CHART OF FISH MOVEMENT IN STREAMS FOR COOS BAY DISTRICT B.L.M

COOS BAY DISTRICT BLM

FISH MOVEMENT IN MOUNTAIN STREAMS

COOS NORTH FORK COQUILLE AND SOUTHFORK COQUILLE WATERSHEDS

SPECIES	AGE ACTIVITY	JANUARY	FEBUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
COHO	ZEROS						Move	Down	Stream		Move back into rivers from main trib.		
	1+			Pre	Smolt	Condition							
	SMOLTS					Move	Down	Stream					
	ADULTS										Migrating	Migrating	Migrating
	SPAWNING	Spawning									Spawning	Spawning	Spawning
	HATCHING			Hatching									
WINTER STEELHEAD													
	ZERO						1	1	1		2	2	2
	1+						1	1	1		2	2	2
	2+						1	1	1		2	2	2
	SMOLT					Move	Down	Stream					
	ADULT		Migrating	Migrating									Migrating
	SPAWNING	Spawning	Spawning	Spawning									Spawning
	HATCHING			Hatching	Hatching	Hatching							
CUTTHROAT TROUT	0												
	1						1	1	1		2	2	2
	2						1	1	1		2	2	2
	3						1	1	1		2	2	2
	4						1	1	1		2	2	2
	5						1	1	1		2	2	2
	6						1	1	1		2	2	2
	SMOLT	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream
	ADULT	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream	Move Down	Stream
	SPAWNING	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning	Spawning
	HATCHING		Hatching	Hatching	Hatching	Hatching	Hatching	Hatching	Hatching	Hatching	Hatching		

NOTE:
#1 = Movement down stream.
#2 = Movement back into the river from main stream.

BARRIERS TO MOVEMENT OF FISH

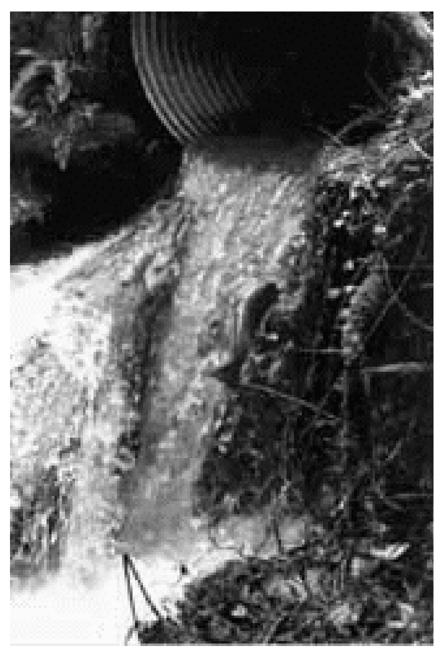
XV. Excessive drops at culvert outlet or inlet creating jumps.
XVI. High velocity or sudden changes in velocity at the culvert inlet, outlet, or within the culvert barrel
XVII. Inadequate depth within a culvert barrel
XVIII. Turbulence within the culvert
XIX. Debris accumulation at a culvert inlet
XX. Lack of resting pools at the culvert inlet, outlet, or within the barrel.

Delays and barriers due to stream crossings can be divided into three different categories each with different potential impacts to fish. See the table below.

Barrier Category	**Definition**	**Potential Impacts**
Total Barrier	Impassable to all fish at all times	(1) Exclusion of fish entirely or from portions of a watershed (2) Isolation of fish populations upstream of a barrier.
Partial Barrier	Impassable to some fish at all times	(1) Exclusion of certain fish species or ages entirely or from portions of a watershed. (2) Isolation of certain fish species or ages upstream of a barrier
Temporary Barrier	Impassable to all fish some of the times	(1) delay of Movement beyond the barrier for some period of time

EFFECTS OF FISH BARRIERS IMPEDIMENTS

Stream channel crossings by roads have been the cause of serious loses of fish habitats due to improperly designed culverts. Studies have indicated this loss of habitat has had the greatest effect, of all the forest management activities, on fish populations. Thousands of culverts have been identified to date that are barriers.



A photo of fish trying to enter a perched culvert. Photo downloaded from San Diamas Web Site.

Partial Fish Passage Blockage

The definition is defined in Oregon as a "stream crossings because of their design, maintenance, or condition are not allowing for juvenile salmonid fish passage. Juvenile salmonid fish require:

- A. Velocities of 2 feet or less
- B. Less then 6 inches of outlet perching
- C. Little to no inlet Constriction or drop
- D. Be free of debris which would concentrate flow
- E Have flow depths greater than 12 inches or has a simulated natural streambed similar to natural channel conditions.

Causes of Partial Blockages

XXI. Bare culverts can be partial blockages under the following conditions:

- A. The slope is greater than 0.5% without back-watering
- B. Residual pools less than 6 inches below the outlet.
- C. The diameter or span is less than 50% of the natural bankfull channel.
- D. The culvert is more than 100 feet long
- E. Outlet back-watering causes less than 12 inch depth of water in pipe.

XXII. Embedded Culverts can be partial blockages.

- A. A variety of material should form a simulated natural channel. There should be evidence of deposition and reworking of smaller materials.
- B. There should be no outlet drop.
- C. The inlet should have sediment, not a sudden drop.
- D. The culvert width should be at least 90% of the bankfull channel width to prevent channel constriction, channel scour, and drops from occurring.

XXIII. Bridges and Open Arch Culverts can be partial blockages

- A. Debris builds up in the structure causing a constricted flow or high velocity
- B. The structure is too narrow such that flow is constricted and high.
- C. The base of the structure is on solid rock such that substrates do not collect

Total Fish Passage Barrier (not the same as guidelines for adult passage)

The definition in Oregon for total blockage for assessment work is a "stream crossings because of their design, maintenance, or condition are not allowing for adult salmonid fish passage." Adult salmonid fish require:

- A. Velocities of 10 feet or less
- B. Less then 12 inches of outlet perching without a pool
- C. Less than 4 feet of outlet perching with an adequate pool
- D. Be free of debris which would concentrate flow
- E Have flow depths greater than 8 inches or has a simulated natural streambed similar to channel conditions in the natural channel.

Causes of Full Blockages

Bare culverts can be partial blockages under the following conditions:

- A. Slopes greater than 4% without back-watering

B. Slopes greater than 6% with back-watering, no jump and un-back-watered lengths less than 50 feet.
C. The diameter or span is smaller creating excess velocities in pipe.
D. The culvert is more than 200 feet long
E. The residual pool is less than 2 feet deep or 1.5 times the height of the drop at the outlet whichever is less.

Embedded Culverts can be full blockages.

F. A variety of material should form a simulated natural channel. There should be evidence of deposition and reworking of smaller materials.
G. There should be a minimal outlet drop.
H. The culvert width should be at least 50% of the bankfull channel width to prevent channel constriction, channel scour, and drops from occurring at the outlet.

Bridges and Open Arch Culverts can be partial blockages

I. Debris builds up in the structure causing a constricted flow or high velocity in excess of 15 to 20 feet per second.

EVALUATION OF CULVERT FOR BARRIERS

Barriers to fish passage exists in degrees at most culverts and structure crossings. Barriers also exist in nature in the form waterfalls, debris blockages, beaver dams etc. As land managers we are attempting to remove those that are man made and most particularly at stream road crossing structures.

What is a barrier and when is it important to remove it? This is still a manner of opinion. I recently visited a fish structure built by Oregon Fish and Wildlife in a stream near Coquille. The structure was a FastTrap and was made by placing a concrete slab across the stream with a trap on one side. The lip of the slab was approximately four to six inches above the stream bed creating a small waterfalls in miniature. Water crossing the slab was about an inch deep when I was there. Is this a barrier? Should it be removed?

The fish structure is a barrier of course and it can be removed by construction of a downstream boulder weir that would back-water the slab during low flows.

The need for an inventory of man-made barriers has to be the first step to developing a recovery program. There are numerous forms available for this purpose and more being developed every day as local watershed councils and government agencies assess their particular program. Once inventoried, agencies can then prioritize the sites and initiate a strategy for repair or replacement.

Agencies such as the USFS and BLM are identifying sites in the Watershed Analysis process part of the Northwest Plan.

Steps in Restoring Fish Passage in a Basin or Land Ownership

Find and Prioritize problem road/stream crossings

D. Get information about stream and other conditions at crossing to be restored
E. Decide if installation can be repaired or improved or must be replaced
F. Decide on design strategy; based on the information collected
G. Prepare a design

H. Install new road/stream crossing structure
I. Monitor and Maintain road /stream crossing structure

Inventory and Assessment of Culverts on Fish Bearing Streams

Most agencies have forms and procedures in place for culvert inventories. Those inventories will logically be posted in the future on a Web-based GIS system. The technology for that is already in place or being proposed.

The State of Washington has published an excellent manual on assessing barriers in a stream. It has forms and a documented procedure for assessing streams.

A second good source of material is the work being published by the "stream team "at San Dimas. Their web site is noted below. They have links to the manuals developed by the State of Washington and also forms that are used with an assessment program called FISHXING.

http://www.stream.fs.fed.us/fishxing/

The Oregon Road stream Crossing guide also contains a sample form for evaluation of culverts as blockages.

Evaluating culverts with "FISHXING"

A good procedure for evaluating an existing culvert for fish passage is to use a program developed by the Sand Dimas Testing Center and Humboldt State University. The program is called Fishxing and is available on the Web as free software. The documentation for its use is also on the web. Using the appropriate tools, one can determine when a culvert is a barrier.

The program allows a user to select a fish species, quantify its swimming ability and to then compare that ability against a culvert's flow characteristics. From that, comparison charts have been developed to show the extent of the time a structure is a barrier to fish passage.

The program considers the following

- Species of fish
- Swimming ability of fish
- Condition of fish
- Characteristics of Culvert: Shape, length, size
- Roughness of Culvert
- High Fish passage flow
- Low Fish passage flow

This program is an excellent tool for checking culverts for barriers and is recommended for selection of projects for replacement or retrofit. It can be used for some designs where the "hydraulic design " method is appropriate. The web site includes some good references and table. The table on the following page is an example of the data available on this website to aid in culvert evaluations

Sullivan Gulch (January 1999)

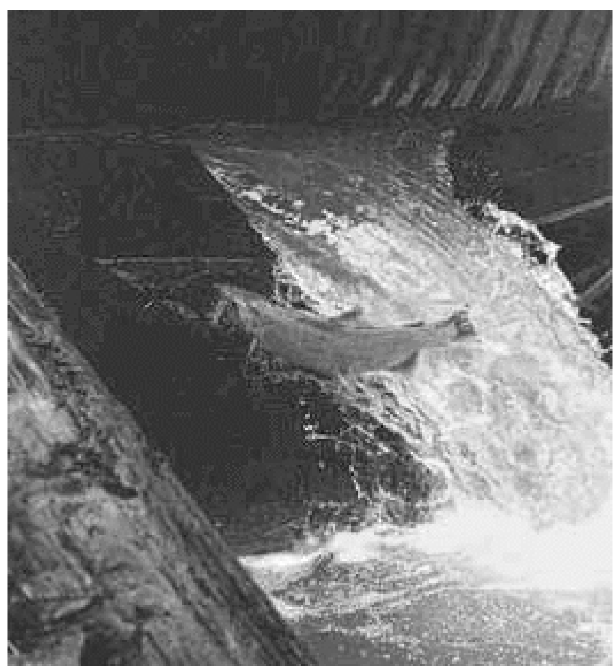


Photo downloaded from Web Site. Picture of fish trying to enter a pipe with a baffle at its outlet.

"The swimming abilities for many different species have been tested in laboratory apparatuses and observed in field studies." The table below lists the reported range of observed swimming speeds for different species along with the default swim speeds used in FISHXING, and references.

Fish Species and Age Class	Swimming Ability Reported Range	Default used in FishXing Reference
Bigeye Shiner	1.08 ft/s for 10 min (90% success)	Prolonged = 1.00 ft/s
	1.18 ft/s for 4 min (95% success)	Burst = 1.30ft/sLayher and Ralston, 1997
	1.28 ft/s for 2 min (90% success)	
Brown Trout	Prolonged (2.3 ft/s - 7.5 ft/s)	Prolonged = 7.5 ft/s
	Burst (7.5 ft/s - 12.2 ft/s)	Burst = 12.2 ft/sBell, 1991
Carp	Prolonged (1.5 ft/s - 4.0 ft/s)	Prolonged = 4.0 ft/s
	Burst (4.0 ft/s - 14.0 ft/s)	Burst = 10.0 ft/sBell, 1991
Central Stoneroller	Fork length range: 1.46 in -3.94 in,	Burst = 1.20 ft/sLayher and Ralston, 1997
	Swim speed ranged: 1.21 ft/s* - 1.50 ft/s*	
Chinook	Prolonged (3.4 ft/s-10.8 ft/s)	Prolonged = 10.8 ft/s
	Burst (10.8 ft/s - 22.4 ft/s)	Burst = 22.4 ft/sBell, 1973
Coho	Prolonged (3.4ft/s - 10.6 ft/s)	Prolonged = 10.6 ft/s
	Burst (10.6 ft/s - 21.5 ft/s)	Burst = 21.5 ft/sBell, 1973
Cutthroat Trout	Prolonged (2.2 ft/s - 4.0 ft/s)	Prolonged = 4.0 ft/s
	Burst (4.0 ft/s - 13.5 ft/s)	Burst = 13.5 ft/sBell, 1991
Goldfish	Prolonged (0.7 ft/s - 3.5 ft/s)	Prolonged = 3.5 ft/s
	Burst (3.5 ft/s - 5.0 ft/s)	Burst = 5.0 ft/sBell, 1991
Grayling	Prolonged (2.5 ft/s - 5.0 ft/s)	Prolonged = 5.0 ft/s
	Burst (5.0 ft/s - 14.0 ft/s)	Burst = 14.0 ft/s Bell, 1991
Greenei Darter	mean = 1.02 ft/s* s.d.=0.27	Burst = 0.75 ft/sLayher and Ralston, 1997
Redfin Darter	mean = 0.92 ft/s* s.d.=0.37	
Orangebelly Darter	mean = 0.97 ft/s* s.d.=0.37	
Lamprey	Burst (3.0 ft/s - 7.0 ft/s)	Prolonged = 3.0 ft/s
		Burst = 6.0 ft/sBell, 1991
Lamprey	Burst (6.23 ft/s)	Watts, 1974

Large Central Stoneroller	2.17 ft/s for 82 min	Prolonged = 2.20 ft/sLayher and Ralston, 1997
Longear Sunfish	0.62 ft/s for 14 min (100% success)	Prolonged = 0.65 ft/s
Length (50-136 mm)	0.72 ft/s for 6 min (91% success)	Burst = 1.10 ft/sLayher and Ralston, 1997
	1.08 ft/s for 2 min (88% success)	
Pink and Chum	Prolonged (2.6 ft/s - 7.7 ft/s)	Prolonged = 7.7 ft/s
	Burst (7.7 ft/s - 15.0 ft/s)	Burst = 15.0 ft/sBell, 1973
	Estimated from leap heights at waterfalls	
Seined Golden Shiners	swim speed (ft/s)* = 0.563+1.608L(in)	Burst:
	R-square = 0.707	V(ft/s) = 0.563+1.608L(in)
		Layher and Ralston, 1997
Shad	Prolonged (3.0 ft/s - 7.6 ft/s)	Prolonged = 4.5ft/s
	Burst (7.6 ft/s - 14.5 ft/s)	Burst = 9.0 ft/sBell, 1991
Sockeye	Prolonged (3.2 ft/s - 10.2 ft/s)	Prolonged = 10.2 ft/s
	Burst (10.2 ft/s - 20.6 ft/s)	Burst = 20.6 ft/sBell, 1973
Steelhead	Prolonged (4.6 ft/s - 13.7 ft/s)	Prolonged = 13.7 ft/s
	Burst (13.7 ft/s - 26.5 ft/s)	Burst = 26.5 ft/sBell, 1973
Stickleback	Burst (3.0 ft/s - 3.5 ft/s)	Prolonged = 3.0 ft/s
		Burst = 3.5 ft/sBell, 1991
Suckers	Prolonged (2.5 ft/s - 5.0 ft/s)	Prolonged = 5.0 ft/s
	Burst (5.0 ft/s - 10.0 ft/s)	Burst = 10.0 ft/sBell, 1991
Whitefish	Prolonged (1.5 ft/s - 4.5 ft/s)	Prolonged = 4.5ft/s
	Burst (4.5 ft/s - 9.0 ft/s)	Burst = 9.0 ft/sBell, 1991
Juvenile Bighead Carp	mean = 0.81 ft/s* s.d.=0.13	Burst = 0.75 ft/sLayher and Ralston, 1997
Juvenile Salmonids:	swim speed (ft/s) = 0.638L(in)-0.0172	Burst:
Coho, Chinook,		V(ft/s) = 0.0251L(mm)-0.0172
Steelhead, Chum, Pink		Barber and Downs, 1996

* Reported as velocity of failure point, causing swimming to quickly terminate in exhaustion.”

ROAD STREAM CROSSING DESIGN METHODOLOGIES

The following are some of the methodologies used for designing culverts. The preferred method will depend on the site characteristics, alternatives considered and goals for the crossing.

Traditional method: Historically, Culverts and hydraulic structures were selected for efficiently moving water. Designers improved the culverts to increase velocities, and optimize the flow of water. Structures were selected that had reduced roughness, improved inlets, and layouts that minimize the effects of back-watering. These structures were successful for moving water but often created barriers to fish movement upstream. This method of designing is still a good procedure for ditch relief culverts and storm drains which do not have fish passage goals.

"Hydraulic design option (This method or option as defined by WDFW)."requires a culvert be designed based on swimming abilities of a target species and age class. The hydraulic design option can be applied to retrofits of existing culverts as well as to the design of new culverts. Hydraulic open channel flow and hydro logic computations together with specific site data are required for this option."The design can be checked using the FISHXING program noted earlier to verify that the minimum depth of flow and velocity occur when fish are moving."

"Stream Simulation" Procedure: This procedure is to add roughness, set the pipe, or enlarge the pipe such that a natural channel is created or simulated in the culvert. This condition is often preferred for passage of all fish and non fish species.

A. A stream road crossing designed for stream simulation allows unimpeded movement of all fish and wildlife in the stream. We achieve that objective by simulating the characteristics of the stream when fish and organisms are moving. Fish passage is unrestricted. Juvenile fish are assumed to swim through the pipe without jumping. The crossing has a natural substrate through its full length.

B. The preferred crossing will have a natural bottom or substrate. Fish movement occurs between rocks, gravels, and boulders, which provide reduced velocity sections. The channel may be functioning on an average at higher velocities. With a natural substrate, channels will re-grade into small rivulets creating sufficient depth for movement of fish and other organism.

C. During low flow periods the streams may totally dry up in that case movement through the crossing structure will be minimal. Likewise as in a natural channel, there are periods of high flow that the structure or channel will not be passable.

D. There are various design options for stream simulation.

   1. "No slope method": The Washington Dept. of Fish and Wildlife coined this phrase for those designs where a culvert is placed flat with 20 percent of the culvert countersunk. The goal is to create a sloping channel inside the culvert. See Chapter Four.

   2. Herringbone baffles Design: This design was developed by the Coos Bay District of the BLM to collect substrates in a culvert. Culverts have a natural substrate though them or at least partially through them. See Chapter three. Robison's Embedded pipes: George Robison, Oregon Dept. of Forestry embedded pipes with Rocks to create roughness. See

Chapter four.

3. Buried Culvert Designs: This is a traditional concept where a culvert is bedded and filled to 50% of its capacity with rock.
4. Full Simulation; Stream Simulation method proposed by WDFW wherein the culvert is designed wider than the natural channel to simulate the changing character of in nature. See Chapter Four.

I. “Fishway Design Procedure”: This method is to design a series of sloping weirs in the structures that satisfy fishway design criterion for pool and weir fishway designs. This procedure is “not for amateurs and requires a good knowledge of design flows when fish are moving. When used correctly culverts appear to have a cascade of ripples from beginning to end that allow the movement of all fish species through a structure. See Chapter Five.

Other Considerations in Selection and Replacement of Structures at road crossings:

Amphibian movement and dispersal

Most existing culverts, even those designed to allow juvenile salmonid passage ***may function*** as barriers to upstream movement and dispersal of stream and riparian associated amphibians. Due to the extensive road network, culverts are abundant, and could isolate the less mobile amphibians in small meta-populations. These meta-populations are vulnerable to human or natural disturbances, and the barriers to movement could prevent amphibians from decolonizing these impacted habitats once they recover. There is limited knowledge at this time on their capabilities accordingly. Prudence would dictate when they are in an area that the best passages are considered.

Movement and dispersal of fish

Many existing culverts only allow adult salmonid passage while others allow for fish with higher swimming speeds. Those culverts may function as barriers to juvenile or non-salmonid fish species such as sculpin or dace, as well as other aquatic species including crayfish and aquatic invertebrates. These species may be incapable or unlikely to enter a culvert which isn’t in direct contact with the stream bottom, or they may be incapable of moving through a structure which does not provide a natural surface stream bottom.

Water Quality, Wetland and Riparian Habitats

Undersized, rusted, and/or minimally maintained culverts and surrounding fills have a potential for failure during high precipitation events (20, 50, and 100-year events). A majority of the roads are not maintained to design standards due to budget constraints. Additionally, these failing culverts would probably only be replaced on an emergency basis, that is after the road has failed. These situations typically lead to excessive sediment delivery to the aquatic system resulting in impacts to macro-invertebrate, amphibian, and fish populations. Additionally, culverts installed as emergency replacements are often inadequately designed to address the movement and dispersal needs for aquatic organisms.

Large Material Delivery

Due to the extensive road network present on public and private lands many streams are crossed multiple times by roads, substantially affecting the quality and continuity of aquatic ecosystems. Coast Range streams depend heavily on debris slides and torrents for the recruitment of in-stream material, especially coarse sediment and wood, to provide aquatic habitat components. This large material is also critical in the dissipation of stream energy. Roads and stream crossing structures function as dams, primarily during storm events, that constricts flow through a single narrow outlet. These constriction points cause deposition and channel widening at the inlet and increased velocities and scours at the outlet.

The damming effect of road structures prevents the transportation of material down the channel and may limit the function of the flood plain. Large material that would be delivered to the stream channel is also trapped when debris torrents or slides are stopped by the roadbeds.

Typical Objectives of Structures at road/stream crossings

2. To maintain, protect, or improve the existing infrastructure of our transportation system.
1. Reduce barriers to movement and dispersal of stream-associated amphibians and invertebrates.
2. Reduce barriers to movement and dispersal of anadromous and resident fish.
3. Reduce the risk of culvert failure and input of large quantities of fine sediments from the road fill to the stream systems.
4. Properly size and install culverts to withstand a 100-year flood event. This should include storm proofing of the roadway should the inlet become plugged.
5. Improve the transport of coarse sediments and woody debris material.

In stream simulation the stream should make a seamless transition from the natural channel through the new structure and into the channel below.

Stream Dynamics

Streams should be though of as a system with a given amount of energy and discharge. The discharge is a function of three parameters: channel width, channel depth and channel velocity. Since the discharge is constant at any given point, a change in any given parameter must be balanced by a change in the remaining parameters. Understanding this balancing act is the key to achieving stream simulation. The width, depth, and velocity of the channel must be maintained through the crossing structure to keep the system balanced so that it will look the same from above and below the crossing structure. Changing any of these parameters will affect the others. Velocity and depth are affected by the streams roughness slope and cross sectional area. The table below will help illustrate this concept.

FACTOR	VELOCITY	DEPTH
Increasing Channel roughness	**decrease**	**Increase**
Increasing Cross Sectional Area	**decrease**	**decrease**
Increasing channel slope	**increase**	**decrease**

A further discussion on stream dynamics and hydraulics is included in Chapter two of this manual
Crossing alternatives

For new stream crossings, the following structure types are proposed in order of preference. Each of these structures is reviewed in details in subsequent chapters to this report. Additionally a brief summary of the pros and cons of each of the structure types is included below.

1. Fords allow complete passage of all woody debris and aquatic organisms

2. Bridge (flow through design with no approach embankment into the main channel).

3. Open Bottom Culverts or “three-sided boxes”.

4. Culverts which simulate the existing channel by holding or collecting a natural substrate. Examples of these designs include buried culverts or culverts with roughening baffles.

5. Culverts with sloping weirs and roughening baffles which are designed to create backwater pools not collect substrates.

6. Fishway or ladders designed to pass adult fish within a specified flow range.

Fords

Like a bridge the ford allows complete passage of woody debris and the deposition of a natural substrate across the channel. If installed correctly, a ford should allow the stream to maintain a constant gradient through its particular reach. Fords are used commonly in the South-Western Portion of the United States where roads cross streams that have flashy characteristics. In the Pacific Northwest streams have flows year round and traffic will normally cross open water. This creates concerns with public safety, transport of noxious weeds and has a potential for road related sedimentation to enter the stream. Fords are recommended when roads can be managed. They are very reasonably priced alternatives that meet all passage and stream simulation concerns.

The Edson Creek Ford

Bridges

A bridge will normally span the full stream channel and allow a stream to cross unobstructed below. In that vain bridges meet the majority of stream /road crossing objectives. During major flood events bridges will often prevent the movement of woody debris as debris hangs up on their superstructure or substructure. For stream simulation designs bridges are the preferred alternatives.

The downside of bridges are their costs. Recent projects on the Gifford Pinchot National Forest have given hope that low-cost bridges may be obtainable in the future. Railroad cars are used on private land and offer low-cost superstructure options. Railroad car bridges are not alternatives for public roads. A railroad car bridge can be load rated and once rated will potentially satisfy the structural design criterion required by public agencies.

For some sites a bridge is not a good choice. A bridge can create a barrier to movement of some fish if the stream gradient under the proposed bridge is very steep or on a bedrock ledge. Existing culverts streams are often have aggraded at their inlets and degraded at the outlets. Connecting the two stream segments with a rocked chute could create a barrier to passage. In those circumstances a pipe that allows fish passage may be the best option.

Open Bottom Structures

An open bottom structure has many of the same benefits as a bridge. They do not alter the size, shape and gradient of the stream. They normally are placed on concrete footings or on metal footings plates. Open bottom structures are often the only reasonable alternatives to a pipe arch for achieving stream simulation on steeper sites. By definition they have a natural bottom Common types of these structures include: Half round pipes, multi-plate arches, concrete “three-sided boxes” and concrete arch structures.

Open bottom structures are an excellent alternatives when bedrock is near the surface. Footings can be placed on the bedrock with a minimum of rock removal.

Open bottom structures allows the passage of most woody debris. During major events they can plug. Unlike a bridge an open bottom arch structure will normally not completely bridge the natural channel. Large woody debris will build up behind them creating the same risks as culverts of a road failure. Metal arch culverts are particularly sensitive to complete failure if overtopping occurs. Concrete open bottom structures such as “three-sided boxes” can withstand major flood impacts and overtopping. The concrete structures also require less cover than do the metal structures. Concrete open bottom structures are often advertised as “short span bridges.”

The second concern with open bottom structures is their sensitivity to scour, settlement, or damage from erosion around the footings. Their design requires careful details to the width of the channel necessary to retain the protective rock around the footings. Inspection of rock works and compaction is critical to their success. On soft sub-grades open bottom structures are not recommended as their footings require a relatively inelastic base. When using an open bottom structure a geologist report is recommended to verify the base materials.

Pipe Arch Culverts fully buried, embedded or fitted with roughening baffles

The above methods are intended to trap gravel or substrates in the culverts for their full length and width. The width of the buried substrate should approximate the active channel of the existing stream or a similar reach. Pipe arches are recommended because they have wider inverts and require less excavation and smaller sizes than do circular culverts for achieving the desired channel width. This alternative is considered a stream simulation design in that its goal is substrate retention.
A criterion for success includes:

1. An acceptable size substrate is maintained for the full length and width of the structure. That substrate allows fish movement during low flows and higher velocities and also movement of non fish species through the structure.
2. The inlet width is unrestricted. Flow into the inlet of the culvert is sub critical and not turbulent when juvenile fish are moving through the culvert. Minor turbulence is acceptable during periods of adult passage only.
3. The outlet is backwater allowing a swim-thru condition for fish entering the outlet of the culvert.

The completed structure will have the following characteristics.

1. A method of retaining substrates in the culvert such as the herringbone baffle design, seeding the pipe or embedding the pipe. (See details later in this report).
2. The width of the structure at the level of the top of the substrate should be at least as wide as the active channel width.
3. Seeding or embedment of rock is used for all reaches of the culvert which do not achieve natural retention.
4. The culvert approximates closely the natural stream gradient.
5. Downstream control weirs or other systems are used to backwater flow into the culvert.

If used correctly, pipes will trap natural substrates in the bottom of the culvert, thus mimicking the natural streambed within the culvert and providing habitat continuity between the stream above and below the road crossing. If the gradient, substrate characteristics, and flow conditions within the structure are similar to those of the stream channel above and below the culvert, the ability for aquatic species to move upstream should not be limited by these structures. During summer flow these designs allow the flow to cut a channel through the substrate as occurs in the natural streambed. This channel allows for fish movement at low flows when sufficient water for movement is available in the natural stream channel above and below the structure. Amphibians and invertebrates should be able to move either across the moist exposed substrates, or in the water course, depending on stream flow conditions.

These designs are normally significantly less expensive than bridges or open bottom arch alternatives. On large pipe arches that difference becomes less and arches may offer better option.

In areas of soft foundation materials a pipe arch may be the only safe structure to install without having to invest in an extraordinary foundation design. In general pipe arches are the preferred alternative for most road crossings because of the ease of their installation and lower costs.

Pipe Arch Culverts constructed with a sloping weir fishway:

A culvert installed with a sloping weir fishway does not attempt to totally simulate a natural stream. The fishway is modeled as cascading pools between the weirs. Fish movement is unimpeded. We have attempted to refine the design to collect some substrate. Many of our more recent designs do trap substrates. Under that condition they are acting more as pipes with rock collectors than as pool and weir fishway. In either case they have provided passage for juvenile and adult fisheries when the fish are moving. This is a good design for fish passage on steeper slopes. These structures are also good candidates for grades more than 5% up to 14%, when other pipe arch designs are suspect. They can be placed with minor or no risk on soft sub-grades. These structures offer a reasonably priced road crossing that can be installed quickly with a minimal impact on public road use.

Criterions for the success include:

1. The fishway is designed to create a series of interconnected pools through the pipe. Where portions of the pipe are back-watered, those pools will eventually fill with substrates. The back watered portion of the pipe acts in stream simulation mode similar to culverts with baffles noted above. The pools are designed to provide resting areas during higher flows. Plunging flow or stream simulation is maintained within the flow range that fish are moving through the structure.

2. The inlet width is unrestricted. Flow into the inlet of the culvert is sub-critical and not turbulent when juvenile fish are moving through the culvert. Minor turbulence is acceptable during periods of adult passage only.

3. The outlet and each weir are back-watered allowing a swim-thru condition for fish entering and moving through the culvert.

The Completed Structure will have the following characteristics.

1. Fishway weirs designed to provide plunging flow when fish are moving.
2. The width of the structure at the level of the top of the substrate or weirs should be at least as wide as the active channel width.
3. Downstream control weirs or other systems are used to backwater flow into the culvert.
4. Fishway weirs are sloped to allow passage of woody debris material through the culvert.
5. Notches are placed in the weirs to allow juveniles to move in areas of very low velocity.

Pipe arch culverts with sloping weirs have unique design requirements. See Chapter 5 on Sloping Weir Fishway for details.

Evaluation of Alternatives

The evaluation of alternatives is normally done in the federal sector as an interdisciplinary team (ID team) who document their review in an “environmental assessment” (EA.). An evaluation report is recommended for each site. A typical report might include the following:

1. Include a sketch of the site with an accurate profile of the stream reach above and below the structure.

2. Provide a brief description of the site with photos. Include a description and assessment of the barriers that presently exist at the site
.

3. Describe each alternative. Add sufficient information for the team to make their assessment, tailor this information to the team’s experience to avoid writing long reports over and over again. A spreadsheet evaluation is often sufficient for most teams. Describe how the alternative will resolve the barriers at the site.

4. Provide a cost estimate of each alternative. Most agencies prefer a present worth cost analysis that include maintenance, replacement costs, and risks of failure. Discount to present worth at 6% and 0%.

3. Describe the biological impacts of each alternative and their relative importance. Consider the following.

- A. Anadromous fish passage both upstream and downstream
- B. Resident fish passage juveniles and adults.
- C. Movement of non fish species through system.

4. Describe the maintenance requirements of each alternative should be quantified in measurable units such as in workdays per year. Some designs such as an Alaskan Steep Pass may require daily checks and cleaning.

5. Make a time line for the project. Include this in your time line:

- A. What permits are required and when they can be expected.
- B. What is the available construction work period. Most areas have in stream work periods and wildlife restriction that will affect the project.
- C. When funds need to be obligated.
- D. Designs should consider the availability and sensitivity of inspection to their success.

6. Review the geology of the crossing.

A. Sufficient soils’ data is needed to evaluate alternatives. For instance on soft or weak soils an open bottom structure with a concrete or rigid footing will require significant engineering to resolve concerns with settlement. A flexible structure at the same site such as a pipe arch can withstand settlement with minor re-engineering.

B. Bedrock and boulders will change alternatives. If bedrock is near the surface an open bottom structure may be the only feasible alternative. Blasting is often not an acceptable option or may cost more than the benefits from other alternatives.

7. Field Review final Design.

As a final check on the process the EA team should field check the preferred alternative. At the time of that review the proposed structure should be staked. Staking should indicate where all four corners of the structure will set, the proposed cut or fill at each of those corners. The location of the downstream control weir, the perimeters of the waste and/or borrow sites, and the location of the upstream de-watering pond.

Overviews of major Alternatives

The chart below compares the effectiveness of major alternatives.

STRUCTURE	Retain Natural Stream Sbstrate Throughout full length of Structure\	Maintain Unimpeded Upstream Access Through Structure for All Aquatic Species	Pass Gravel and Debris through structure	Constructability on soft foundations	Constructability on rock foundations	cost efficiency 10= high, 0 = low
Fords	Effective	Effective	Very Effective	Very Effective	Very Effective	3
bridges	Effective	Effective	May limit during very peak events	Very Effective	Very Effective	9- new designs may reduce
Open Bottom Arch or three sided box culverts	Effective	Effective- if width correct	Partially effective	not recommended	Very Effective	6 to 7 for metal, 9-10 for concrete
Embedded,sunken or Pipe Arches with roughening baffles	Effective	Effective on lower grades	Partially effective	very effective with proper design	marginal may require blasting, depends on rock	4-GETS HIGHER ON BIGGER STRUCTURES
Pipe Arch with sloping Weir Fishway	Ineffective- may hold substrate on lesser grades	Effective for all fish passage, may limit non swimming species	Partially effective	very effective with proper design	marginal may require blasting depends on rock	4-GETS HIGHER ON BIGGER STRUCTURES

Retrofitting Existing Structures

The following retrofit alternatives are recommended for improving an existing culvert. These repairs are not expected to provide full passage but act as an interim plan. Examples of pipes retrofitted with lexan weirs are included in the case studies.

1. Add roughening baffles to existing culverts to help retain natural substrates and provide low or dead velocity areas.

2. Add sloping weirs or a combination of baffles and weirs to culverts when grades are not appropriate for roughening bafflers alone.

3. Add a second pipe adjacent to the existing pipe designed with a fishway
.
4. Add rock works on the outlet of pipe to allow fish to enter pipe via a series of boulder weirs or a rocked channel.

5. Construct rock weirs at the outlet so as to allow backwatering into the culvert.

6. Construct a fish-way or fish ladder into the existing pipe:

   A. Concrete ladders designed as a side channel to main pipe with a series of pools and jumps

   B. Grades up to 6% percent on very wide culverts add a structure to an outlet with roughening baffles.

   C. Add sloping weirs when the culvert grade is greater than 6 percent or the culvert is less than the natural channel.

   D. Consider a Denile or Alaskan type I fish pass when Grades are in excess of 13%.

Preparing preliminary designs

The following minimum information should be included in the design of the preferred alternative.

1. A site map of the crossing showing:
    - A. The profile of proposed stream crossing
    - B. Contours or stream profile information extending several hundred feet upstream and downstream
    - C. Stream bed conditions
    - D. Estimate of natural stream width

2. Hydrology of Crossing

    - C. Design flows: Q100, Q50, Q10, Q2 using several methods.
    - B. The estimated high monthly flows and low monthly flow when fish are moving. Include a separate range for adult and juvenile fish if they are different.
    - C. Local information such as proximity of dams, other rivers, previous flood history, etc.

3. Estimate the potential of a debris flow plugging the culvert;

4. Stream Channel Characteristics: Define the channel characteristics.

    - A. Can the inlet be down cut?
    - B. Best location for downstream control structure
    - C. What is the desired skew of the channel?
    - D. What is desired gradient of the channel after the repair?
    - E. What size materials are in the channel and what is the expected size in the culvert structure. See (7) below.

5. Fisheries or biological concerns at the site. What anadromous fish are in the stream and when are they moving. Are there any non fish species in the stream that deserve special considerations.

6. Storm proofing or diversion potential concerns at the site.

7. Estimate the expected depth the channel will degrade or regrade at the inlet and outlet. This estimate should include a commentary on substrate movement through the stream. Streams that are very low in the drainage that daylight into estuaries will have a totally different substrate movement than streams higher in the drainage.

General Design Recommendations for Replacement Projects

The following design recommendations are proposed for replacing stream crossing structures. The preferred structure is one that provides a natural stream substrate.

1. Culverts should be sized approximately as wide as the active stream channel to maintain the natural stream bed width and water velocity within the structure.

2. Install the culvert's at or slightly below the natural stream grade to improve substrate deposition and retention. To maintain a suitable gradient, this may require countersinking the inlet below the natural stream bed. This action needs to be carefully evaluated at each site to determine the potential for channel head-cutting.

3. Install culverts so the outlet is in direct contact with the natural stream bottom to provide access for amphibians, fish, and invertebrates into the culvert. The outlet also must be back watered from a downstream structure at least 6 inches and ideally a foot.

4. Embed rock, install baffles or other devices inside the culvert to promote deposition and retention of natural substrates such as gravels and cobbles in the culvert. The substrate will allow passage through culverts of amphibians, fish, and invertebrates.

5. In addition to a downstream control structure consider placing Boulder clusters or large woody material in the channel to encourage deposition of sediments.

6. A control weir ***must be installed*** below all structures that restrict the stream channel. T he only structures' exempt from this would be bridges. Place the "control weir" approximately three diameters from the outlet of the culvert. The outlet of the pipe is than placed 6-inches to a foot below the top elevation of the "control weir" weir. A backwater pool is created that floods the outlet of the pipe. That pool provides a swim-thru entrance for fish moving upstream into the pipe and an energy dissipation pool during peak events. Without this weir the stream will down cut at the outlet eventually leaving a perched pipe. A bridge is the only structure in this author opinion that will not restrict flow. We recently installed control weirs at bridge sites to prevent channel regrading.

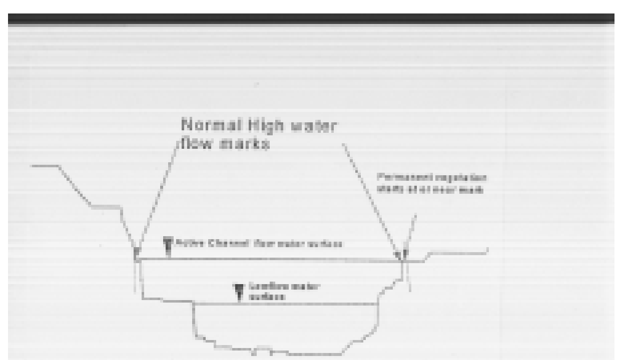


Figure 10. Highwater flow marks and active channel width schematic.

Suggested Best management practices recommended for all Projects

These are offered as minimum considerations in addition to those required by the various regulatory agencies. See copy of Oregon's Conservation BMP in an appendix to this report.

1. Define what water quality controls will be required at the site. Add an additional pay item in the contract for this work if required work is out of the norm. Diversions of flow around the project may require check dams, high volume pumps, sediment control ponds and silt fencing. Provide specifics measurable items rather than vague objectives.
2. The Contractor/Operator is required to submit evidence of a Spill Prevention and Containment Plan consistent with Oregon Department of Environmental Quality and Forest Practices Act, Oregon Department of Fish and Wildlife (ODFW), and B.M. guidelines for in/near stream operations. In addition, a spill containment kit shall be present on site during equipment operations.

3. Remove large fills during low stream flow periods. Use silt dams and filters (such as straw bales) to filter sediment from the water. The earthwork should be completed in the dry season, typically mid-June through mid-October. Install the culvert in the dry, or in isolation from steam flows by the installation of a bypass flume or culvert, or by pumping the stream flow around the work area. The bypass reach will be limited to the minimum distance necessary to complete the project. Fish stranded in the bypass reach will be safely removed to the flowing stream.

4. During installation, all fill material removed should be placed at stable locations in such a manner as to avoid sedimentation and aid in soil recovery. Locate permanent and temporary waste areas on the plans and flag on the ground to avoid confusion.

5. Compact all fill materials in accordance with manufacturers' recommendations to ensure soil strength is maintained over culverts.

6. Upon completion of construction activities, all exposed soils and waste areas should be stabilized with a mixture of seed, fertilizer, and mulch. A native seed mix is preferred but often is not available. Locally a mix of an annual and perennial rye is used.

7. The contract should include standard stipulations for cultural resources, hazardous materials, noxious weeds, and special status species.
8. Contract administrators should be familiar with OSHA safety regulations. The contractor foreman should be certified as a "competent person."
9. Wastewater from project activities and construction site de-watering, will be routed to an area outside the ordinary high water line to allow removal of fine sediments and other contaminants prior to being discharged to state waters.

10. Imported fill which will remain in the stream after culvert removal will consist of clean rounded gravels ranging in size from one-quarter to three inches in diameter.